2000 CALFED Science Conference
Session Notes

Climate Variability and CALFED

Session Chair: Michael Dettinger
Session Notetaker: Daniel Cayan

Chair's overview: Climate variability, and its effect, is the biggest single natural environmental driver of the Bay-Delta system. Observed past variations in climate on historical (past 150 years) and paleo- (over the past several hundred years) time scales, and ongoing changes in climate, provide clear evidence that climate variability needs to be addressed as a science topic with important policy implications as the CALFED program proceeds. Improved understanding of the range and mechanisms of climate variability, and of the specific context of CALFED actions and decisions within this variability, is essential if management strategies are to be correctly planned and evaluated.

Monitoring of the Climatic Context of CALFED: Opportunities and Options -
Kelley Redmond, Western Regional Climate Center, Desert Research Inst.

Monitoring the physical manifestations of climate and weather that affect the delta and its biological inhabitants must be carried out and sustained if CALFED actions are to be understood
in their proper contexts. The atmosphere, the watershed and the coastal ocean all contain a rich spectrum of spatial and temporal structure, much of which is incorporated into the variability of the Bay/Delta. Several observation networks, many of which were not designed for climate purposes, are necessary to provide this spatial and temporal information. The integration of varied existing data sets and data collection programs (scattered throughout different agencies and groups) is complex and requires planning and support. Methods for more easily and efficiently accessing data archives are needed. Acquisition, storage, distribution, display, and manipulation of archived values are currently available, but to varying degrees of success and effectiveness; better infrastructure would benefit a spectrum of scientists and managers.

Sierra Nevada snowpack -- the crucial source of freshwater to the San Francisco Bay -
Frank Gehrke, DWR.

The amount of water accumulated in the Sierra Nevada is the major contributor to fresh water feeding the San Francisco Bay/Delta. Snow accumulation in the high Sierra usually reaches its apex around late March or early April, but from year to year, the timing changes by weeks and the maximum accumulation often varies from its long-term average by +/-50%. A substantial fraction of the watershed's snow covered area lies in the moderate elevation zone that would be vulnerable to increases in temperature, so global climate change could produce a marked decrease in the natural storage that is provided by the seasonal Sierra snowpack. A critical observational program is the California Cooperative Snow Surveys, which maintains a network of over 300 human-observed snow courses and over 100 automated recording snow sensors. A comprehensive effort to gage the snow accumulation in California by measuring the depth and water content of the snow in a set of regularly monitored snow courses was begun in 1929, provoked by the threat of drought and the need to survey the volume of runoff that could be expected from the snowpack. Continuously recording snow sensors have been introduced more recently, generally beginning in about 1980. Very large Sierra snow accumulation years such as 1952 and 1983, and very poor snow accumulation years such as 1977 and 1988 were associated with persistent, large scale climate anomalies.

The Hydroclimatology of California Floods and Droughts - Daniel Cayan, Scripps Institute of Oceanography and USGS.

Floods and droughts are an important part of the climate of the Sacramento and San Joaquin drainage basins. Larger scale Pacific basin atmospheric circulation systems are always involved, but unfortunately, there is no one unique pattern that causes floods and especially droughts; the 1987-1992 drought was marked by several different large-scale climate conditions, including both El Nino and La Nina. Large floods have gotten larger in the last 3-4 decades in some of the major Sierra Nevada streams. Proxy high-resolution paleoclimate data (tree rings, sediments, etc) and numerical models are two important vehicles to extend the rather short instrumental record of drought and floods. Under climate change, we could experience higher winter floods due to more rainfall runoff and rapid snowmelt. The summer dry regime could become more intense if streamflows recede more quickly.

Sierra Nevada runoff into San Francisco Bay - why has it come earlier recently? - Michael Dettinger, USGS

Earlier snowmelt: "Roos ratios" (the fraction of water-year streamflow occurring each year
during the April-July snowmelt period) have declined by ~10% since the 1950's in both the northern and south-central Sierra Nevada. This change was illustrated visual and statistical inspection of the Roos-ratio time series for trends, as well as by comparisons of long-term averages of hydrographs before and after about 1965.

Causes of earlier snowmelt at the basin scale: Winter and spring temperatures have increased in the Sierra Nevada since the 1940s. This warming has been large enough overall to explain the streamflow-timing trends, if we assume that the observed year-to-year streamflow-timing sensitivity to temperatures is also applicable to the long-term trends. This point is demonstrated by regression modeling of streamflow responses to seasonal temperatures during trendy and non-trendy periods. The temperature trends are associated with corresponding trends in winter- and springtime Pacific/North American-sector atmospheric circulations. These atmospheric trends have bent winds (and storm tracks) to be progressively more southerly as they reach the West Coast. This more southerly wind direction has been statistically sufficient to explain the observed warming in California. The changing atmospheric circulations, in turn, have been associated with corresponding North Pacific sea-surface temperature (SST) trends; these SST trends serve to confirm that the atmospheric-circulation trends are real and the air-sea interactions that they imply may eventually help to explain those circulation trends.

Other North Pacific climate influences: Meanwhile, it has recently been discovered that some of this long-term streamflow-timing trend has been masked in recent decades by the decadal variation of the North Pacific climate called (variously) the Pacific Decadal Oscillation (PDO) or the North Pacific Oscillation. This climate oscillation is very similar to (and may be a large part of) SST and atmospheric-circulation trends discussed previously. The primary distinction may well be that this oscillation has been observed to be reversible (i.e., it does not imply monotonic climate trends). For the Sierra Nevada, the recent states of the PDO, in the decades immediately before and after 1976, have resulted in northward and then, more recently, southward displacements of the North Pacific storm tracks arriving at the West Coast.

Redistribution of streamflow to "later" rivers: The recent southward displacement of the storm tracks associated with the PDO has led to subtle changes in the distribution of precipitation in the Sierra Nevada. The resulting overall discharges from the northern and south-central Sierra Nevada have not changed much, but the ratio of the discharges from the two regions has changed markedly. Proportionally more precipitation has fallen in the south-central Sierra (compared to the northern Sierra) since 1976; thus proportionally more streamflow has been generated in south-central Sierra. The south-central Sierran rivers however drain much higher mountain basins and thus hold the winter precipitation until much later in the year than do the northern basins. Consequently, the redistribution of precipitation and streamflow into the south central rivers has led to later Sierra-total streamflows.

Consequences for CALFED: The timing of freshwater inflows to the Bay/Delta system is a critical determinant of overall Bay/Delta salinity and health. Thus changes in the timing of generation of streamflow in the Sierra Nevada can have important consequences to CALFED plans and actions. Trends towards earlier runoff imply a redistribution of streamflow from the springtime category of "water resource" into the wintertime category of "flood hazard". If the trends continue unchecked or unrecognized, the ability of CALFED actions to control Bay/Delta salinities while meeting California's flood-management and resource-management needs may be hampered. Notably, the climatic patterns associated with the observed changes in streamflow timing are of a global-scale form that has been called the COWL pattern (Cold Oceans-Warm Lands). The COWL pattern is an important part of both natural climate variability (in which case it reverses itself from time to time) and simulations of greenhouse warming (in which case it does not). Thus, whether the observed streamflow-timing trends in California will reverse themselves anytime soon is an unsettled issue.

Ocean Climate and Variability: Patterns and Implications - Francis Schwing, Pacific Fisheries Environmental Laboratory, NMFS.

Coastal currents, upwelling, and ocean temperatures along the coast of California are strongly influenced by the behavior of the overlying atmosphere, and vice versa, and also vary seasonally. These affect migratory patterns, nutrient availability, predator-prey relations, ocean habitat, phytoplankton, and estuarine conditions experienced by ocean dwelling and anadromous fish. Timing of the spring transition, the location and strength of the subtropical high, the strength and direction and timing of alongshore winds, and fog patterns are among the climate elements directly and indirectly affecting aquatic life which show long term variations during this century. It is evident that there are ties to large-scale climate structure, but there are also numerous subtleties in the interaction.

Natural and Human Influences on Freshwater Flows and Salinity in the San Francisco Bay/Delta Estuary and Watershed - Noah Knowles, Scripps Institution of Oceanography.

The San Francisco Bay-Delta estuary has been the subject of intense scientific scrutiny in recent decades, stimulated largely by concerns about destruction of natural habitat, contamination of the rivers and estuary, and declines in aquatic species populations. Like all estuaries, behavior of the Bay-Delta is linked to the coastal ocean and to the inland rivers, resulting in high variability at many scales. Also, the estuary has undergone extensive human development over the past 150 years, as has its upstream watershed. Current attempts to understand and restore the Bay-Delta's valuable ecosystems are complicated by both natural and human effects on freshwater inflows. In particular, long-term changes in estuarine conditions complicate attempts to understand the estuary's behavior on the basis of short-term studies. Examining long-term estuarine changes and their causes provides a more complete picture of the estuary and its ever-changing climatic context.

One aspect of the estuary's behavior that has undergone interdecadal changes is the timing of the annual salinity and freshwater inflow cycles. The low-pass filtered (10-year cutoff) timing of the annual cycles of both salinity and inflows shows a trend toward earlier cycles from the 1930's through about 1970, with a subsequent abatement of this trend reaching into the 1990's. A breakdown of the changes in freshwater inflow timing into natural (unimpaired) and managed components reveals that both contribute to this pattern, though natural variability dominates the trend toward earlier runoff before 1970 while management effects dominate the trend abatement.

From the late 40's through the mid 70's, the management effect increased in magnitude, coinciding with the period of development of California's massive water projects. After the mid-70’s, the management effect subsided considerably, possibly due to management changes as well as to the extended drought beginning in 1987.

Between the mid-30's and the early 70's, the filtered unimpaired flow signal shifted earlier by about 15 days. Subsequently, this steady trend broke down, replaced by shorter fluctuations. Several natural forcing factors have been identified which contributed to the timing signal. The first of these is a long-term trend toward earlier runoff of Sierra snowmelt, originally identified by Maury Roos (Roos 1987). This trend has since been associated with a spring warming trend (Dettinger and Cayan 1995).

Two additional factors have been identified that affect the timing of unimpaired watershed outflows: the north-south distribution of precipitation and the timing of precipitation. Climate signals such as ENSO and NPO affect the relative distribution of precipitation in the northern and southern halves of the Bay-Delta watershed (Dettinger 2000). This, in turn, affects the timing of watershed outflow, since the two halves have very distinct hydrological behavior and annual hydrograph timing. At the interdecadal scale, NPO forcing is the dominant climate influence in this watershed. Different NPO "phases" correspond to different ratios of northern to southern precipitation and unimpaired flows, reflecting the shift of precipitation distribution associated with this climate phenomenon. This results in a contribution to unimpaired flow timing that oscillates at the multi-decadal scale, with high NPO index associated with later flows and vice-versa.

The remaining factor that contributes strongly to long-term changes in unimpaired flow timing is the timing of precipitation, particularly in the rainfall-dominated Sacramento basin (Figure 2, bottom plot). While the causes of this variability are not known, there is no apparent association
with NPO, so this must be considered a separate effect.

In summary, long-term changes in the timing of the annual salinity and inflow cycles in the Bay-Delta estuary are a result of both natural and managed effects. Natural variability is influenced at the interdecadal scale by three main factors: changes in precipitation timing, a long-term warming trend causing earlier runoff, and NPO-related timing shifts.

It is particularly interesting to note that since 1977, NPO has been in a "phase" which has tended to counteract the effects of the long-term warming trend. Preliminary evidence suggests that NPO may have shifted phase in the last few years. If this is true, and if the warming trend continues, it is possible that a tendency for very early runoff may characterize the next
few decades.

Behavioral Response to Climate Change and the Decline of Striped Bass in the San Francisco Estuary: Importance of Estuarine-Ocean Ecosystem Linkages - William Bennett, UC Davis.

The effects of climate change can be difficult to distinguish from human interventions acting on fish populations within the San Francisco Estuary. We present analyses suggesting the decline in striped bass is related to a period of frequent El Niños and a concurrent shift in the atmosphere-ocean climate (Pacific Interdecadal Oscillation, PDO) beginning in 1976-1977. Previously, the decline of striped bass has been attributed to impacts on larval and juvenile fish due to exporting fresh water, and recently to density dependence during the pre-adult stage. We show that older striped bass (age 6+ years) migrated more frequently to the warmer Pacific Ocean during multiple El Niño events and the PDO shift, reverting to the behavior of native striped bass populations in Atlantic estuaries.

Time series analyses of adult abundance estimates, sport-fishing records, and ocean environmental variables indicate significant associations between a step-like decline in adult abundance in the estuary, and higher occurrence of older adults in the ocean, with a step-like increase in ocean temperatures and relaxation of upwelling. Rises in ocean temperature are also correlated with rates of decline of adult cohorts in the estuary. In addition, reports in the sport-fishing media and by researchers indicate the sudden appearance of substantial numbers of adult striped bass in the Los Angeles area during the recent La Niña in 1997-1998. These results implicate changing ocean conditions as an important factor affecting the residency, and thus apparent mortality of older striped bass in the estuary. Frequent migration from the estuary combined with density dependent survival of pre-adults may be precluding restoration of the estuarine population. This example illustrates the importance of estuarine-ocean linkages and the challenges posed by climate change for management.

Tree-ring Reconstruction of San Francisco Bay Salinity: 1604-1997 - David W. Stahle, University of Arkansas

Blue oak (*Quercus douglasii*) tree-ring chronologies from California are highly correlated with winter-spring precipitation, Sacramento-San Joaquin streamflow, and with salinity in San Francisco Bay. A blue oak reconstruction of salinity explains 81% of the interannual variability of seasonalized surface salinity measured at the Golden Gate from 1922-1952 (Fort Point), a period preceding the massive diversion of freshwater from the Sacramento-San Joaquin system. The reconstruction indicates that the post-diversion salinity extremes witnessed in San Francisco Bay after 1952 have been unprecedented over the past 400 years, particularly during the record California droughts of 1976-1977 and 1987-1992. These recent extremes and the 2.52% increase in average January-July salinity measured at Fort Point from 1953-1994 appear to largely reflect the anthropogenic appropriation of Sacramento-San Joaquin streamflow.

Summary and Conclusions: CALFED Climate Issues:

CALFED is a bold and audacious attempt to exercise adaptive management on a large scale and in a complex sociopolitical environment. To properly evaluate the effectiveness of intervention actions, after observing particular outcomes, we must possess sufficient understanding of system behavior to estimate what would have happened naturally, without intervention. What outcomes were more plausible or possible in the absence of intervention?

The flow of fresh water into and through the Delta is the major driver of much of the non-tidal variability of salinity and other physical and biological properties in San Francisco Bay. The factors which link this flow to climate behavior at all space and time scales, ranging up to the size of the Pacific Basin or even the globe, must be better understood. The degree of predictability of each of these factors must be established.

During times of climate extremes (drought and wet spells), impacts of climate variability on fresh water flow, salinity and presumably other Bay/Delta properties is so large that it overwhelms any counterbalancing influences of human management.

Routine and systematic monitoring of physical and biological variables is vital. The spatial domain relevant to the Bay-Delta area extends to the upper headwaters of the Sacramento / San Joaquin and also includes near-shore ocean conditions. The region exhibits long-term trends in the timing of snowmelt (toward earlier in spring) that need to be placed in wider perspective. The prospect for global climate changes to affect this area highlights the need to be able to detect subtle long-term trends.

In the past fifty years the well-studied flood regime on the American River has undergone a dramatic change toward more frequent very large floods. We have no idea why this has occurred, and do not know whether the next fifty years will relax back to the first half of the 20th Century. Changes of this magnitude in the flood hydrology have enormous implications for the design and interpretation of adaptive management experiments.

Considerable experience with similar (though smaller) programs and projects shows that the vast array of science efforts now underway will request, expect, and eventually demand access to the wide variety of climatic, hydrologic, biologic and physical data that exist. Existing systems for the provision of such information should be augmented to handle the expected demand for such information from the research community and others. Ease of access and interpretation are important factors to consider.

Several long term unexplained trends in temperature and precipitation have been noted for the CALFED region. These may be true monotonic trends, or they may result from slow oscillations between different climatic regimes. In many of the relatively short records available, regime shifts from one 20-30 year span to the next may masquerade as "trends" because they have not been observed long enough. For example, the Pacific Decadal Oscillation can and apparently does produce such behavior, and may have also recently (late 1990s) shifted back to a prior state. Ocean currents very likely respond to such climate shifts on the scale of several decades.

In addition, the variability of climate has increased dramatically since the 1970s. During this short period the state has experienced the wettest and driest individual years in its long history, and the wettest and driest multi-year averages. Each of these, wet and dry, have occurred in the
presence of each of El Nino, No Nino, and La Nina, so obviously there is much to be learned.

Coastal Pacific sea Level responds to multi-scale climate variations and must be understood and predicted; in some cases, sea level rises sharply in response to the same storms that produce excessive precipitation and runoff, so the two phenomena should not be treated separately
in planning for high sea level events or episodes. On top of this, the rate of sea level rise, currently about 15cm/century along the California coast, is expected to accelerate under global warming scenarios. This must be considered in long range planning.

The reasons why central California experiences floods and droughts are not clearly understood, or well predicted. There appear to be differences in the character of floods between the Coast Range and the Sierra Nevada that relate to whether El Nino or La Nina is present. Other factors also must play a role, because floods and droughts occur during periods with and without anomalous tropical Pacific conditions.

We do not have an adequate understanding of the climatic context of the 20th Century. How representative is the period of historical and/or instrumental records of the past millennium? Evidence from sequoias suggests that the 20th Century may have been the wettest in two thousand years. How robust is this conclusion? What are the implications? If true, will this continue? California is relatively blessed with an abundant and widely distributed supply of excellent and even unique natural rainfall recorders, in tree rings and other proxy records. These recordings provide invaluable and detailed information about both spatial and temporal variations in past climates for several hundred individual years, and a diligent and aggressive effort should be under way to learn the climatic lessons these trees have for us. Thus, the ability to reconstruct past interannual variability of moisture and other climatic measures from tree rings and other proxies is invaluable and should be pursued with more extensive collections and diagnostics.